

## Cryogenic properties of aluminum-beryllium and beryllium materials

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### ABSTRACT

Ultimate tensile strength, yield strength, and elongation were obtained for the aluminum-beryllium alloy, AlBeMet162 (38%Al-62%Be), at cryogenic (-195.5°C (-320°F) and (-252.8°C) (-423°F)) temperatures, and for an optical grade beryllium, O-30H (99%Be), at -252.8°C. AlBeMet162 material was purchased to the requirements of SAE-AMS7912, "Aluminum-Beryllium Alloy, Extrusions."<sup>1</sup> O-30H material was purchased to the requirements of Brush Wellman Inc. specification O-30H Optical Grade Beryllium.<sup>2</sup> The ultimate tensile and yield strengths for extruded AlBeMet162 material increased with decreasing temperature, and the percent elongation decreased with decreasing temperature. Design properties for the ultimate tensile strength, yield strength, and percent elongation for extruded AlBeMet162 were generated. It was not possible to distinguish a difference in the room and cryogenic ultimate strength for the hot isostatically pressed (HIP'ed) O-30H material. The O30H elongation decreased with decreasing temperature.

### 1. INTRODUCTION

Space structure design often requires that a material's mechanical properties be determined for cryogenic temperatures. Projects and designers require design mechanical properties for the materials used in their structures at the temperatures and pressures the structures are expected to experience in service. The mechanical properties at cryogenic temperatures for the materials AlBeMet162 and O-30H were evaluated in support of two next generation space telescope programs.

The Lockheed Company developed the first aluminum-beryllium material in the 1960's.<sup>3</sup> In the past decade, due to the desirable performance characteristics of this family of materials for aerospace applications, new alloys have been developed with improved mechanical properties, along with improved processing techniques and process controls for their production.<sup>4</sup> Aluminum-beryllium materials are available in the form of extrusions, rolled plate, forgings, and most recently near net shape investment castings. Desirable characteristics of aluminum-beryllium materials include low unit weight, dimensional stability, high elastic modulus, good vibration damping characteristics, low coefficient of thermal expansion, and the capability to be extruded. These materials are 3.5 times stiffer and 22% lighter than conventional aluminum alloys. Their use is attractive for weight critical structural applications such as advanced electro-optical systems, advanced sensor and guidance components for flight and satellite systems, components for light-weight high-performance aircraft engines, and structural components for helicopters.<sup>5</sup> As these materials become more highly used in aerospace programs, mechanical properties at cryogenic temperatures will be needed for structural analysis. AlBeMet162 is an aluminum-beryllium extruded alloy that was developed by the Brush Wellman Company. It was considered for the entire Integrated Science Instrument Module (ISIM) structure; i.e., box beams, brackets, plates, etc., by the James Webb Space Telescope Project Office. The cryogenic tensile properties for this alloy were evaluated to support the ISIM project for the Goddard Space Flight Center.

The O-30H material is an optical grade hot isostatically pressed beryllium material that is being investigated as the primary mirror material for the James Webb Space Telescope Project by the Marshall Space Flight Center. Remnant O-30H material from the billet used to fabricate the Sub-scale Beryllium Mirror Demonstrator (SBMD) mirror was obtained to evaluate mechanical properties at cryogenic ((-252.8C (-423F)) temperatures for the Marshall Space Flight Center.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 AlBeMet162 Testing

Material and tensile specimens were obtained from the Brush Wellman Company. Flat, rectangular cross-section tensile specimens were fabricated per the cut plan shown in Figure 1 from extruded AlBeMet162 material per SAE-AMS7912, "Aluminum-Beryllium Alloy, Extrusions." The extrusion used to extract the specimens was approximately 5.08 cm x 20.32 cm x 88.9 cm (2" x 8" x 35"). Test specimens were extracted from the extrusion in the longitudinal (L), transverse (L-T), and 45° (45) degree orientations, and from the T/6, T/2, and 5T/6 thickness locations along the length of the extrusion, where T = material thickness.

Twelve specimens were extracted from the T/6 thickness location along the length of the extrusion, five in the (L) orientation, five in the (L-T) orientation, and two in the (45) orientation. Twelve specimens were extracted from the T/2 thickness location along the length of the extrusion, five with the (L) orientation, five with the (L-T) orientation, and two with the (45) orientation. Eleven specimens were extracted from the 5T/6 thickness location of the extrusion, five with the (L) orientation, five with the (L-T) orientation, and one with the (45) orientation. (See Figure 1). The different orientations were tested to determine whether a significant difference in the mechanical properties was discernable at cryogenic temperatures.

Tensile testing was performed in room temperature air, at -195.5°C (-320°F), and at -252.8°C (-423°F) using ASTM E8 procedures. Room temperature testing was performed to verify mechanical properties conformance of the material to those specified in AMS7912. Cryogenic testing was performed to characterize the material properties (ultimate tensile strength, yield strength, elongation) at the subject temperatures.

### 2.2 O-30H Testing

Beryllium material was provided by the Brush Wellman Company. Flat, rectangular cross-section tensile specimens were extracted from the billet per the cut plan shown in Figure 2 from a remnant piece of HIP'ed O-30H material from the SBMD mirror program. Tensile testing was performed in liquid hydrogen at -252.8°C (-423°F) using ASTM E8 procedures. Cryogenic testing was performed to characterize the material properties (ultimate tensile strength, yield strength, elongation) at the subject temperature. The elastic modulus was determined on three samples per ASTM E111, and then the specimens were tested to failure per ASTM E8 procedures.

## 3.0 RESULTS

### 3.1 AlBeMet162 Results

Mechanical property results are shown in Table 1, and Figures 3 through 5. The means of the ultimate tensile strength, yield strength and percent elongation for each temperature and specimen orientation are shown in Table 2. Analysis of variance (ANOVA)<sup>6</sup> were conducted for comparisons of differences between the longitudinal and transverse specimens at -195.5°C (-320°F) and -252.8°C (-423°F), and for comparisons of differences between properties of the same specimen orientation at different temperatures. Due to the limited database, no effort was made to statistically analyze trends between thickness locations.

Mechanical properties at room temperature met the requirements of specification AMS7912 for the ultimate tensile strength and yield strength for both longitudinal and transverse specimens. The elongation met the specification requirement for the transverse specimens, but was below the requirement for one of two longitudinal specimens that failed in the gage length. Analysis of variance (ANOVA) performed on the room temperature data show that the ultimate tensile strength and percent elongation between the longitudinal and transverse specimen orientations are distinguishable, whereas the yield strength between these two orientations was not distinguishable statistically. This is consistent with the properties in the specification for these two orientations.

The ultimate tensile and yield strengths at  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) were higher than the room temperature mechanical properties. ANOVA performed on the  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) data show the ultimate tensile strength and percent elongation were not distinguishably different between the longitudinal and transverse orientations, but the yield strengths were distinguishable statistically. ANOVA showed the  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) properties were distinguishably different from the room temperature properties in all cases except for the UTS/L orientation. For this case, the difference in means between  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) and  $21^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ ) was large and one would expect a statistical difference in means. The reason the means were not distinguishable was because of the extremely large variance in the  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) data.

The ultimate tensile and yield strengths at  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ) were increased over the  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) and room temperature mechanical properties. ANOVA performed on the  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ) data showed the ultimate tensile and yield strengths were distinguishably different between the longitudinal and transverse orientations, but the percent elongation was not distinguishable statistically. ANOVA showed the  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ) properties were distinguishably different from the  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) properties in all cases.

Design values for the ultimate tensile strength and yield strength versus temperature were generated from the mechanical property data, and are shown in Figure 6. The design properties are presented as ratios of the average cryogenic temperature ultimate tensile and yield strength values divided by the average room temperature ultimate tensile and yield strengths obtained during testing. The Figure 6 data represents lower bound properties for both the longitudinal and transverse directions. They do not represent MIL-HDBK-5 A or B-basis properties. To obtain cryogenic properties, multiply the AMS7912 room temperature ultimate tensile strength or yield strength value by the percentage shown in Figure 6.

Design values for percent elongation are shown in Figure 7. These values are based on the AMS 7912 value for room temperature, and on the minimum values obtained during testing at  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) and  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ). Note the poor ductility at  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) and  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ).

### 3.2 O-30H Results

Mechanical property results for the O-30H material are shown in Table 3, and Figures 8 and 9. It was not possible to obtain the yield strengths during testing at the liquid hydrogen temperature. The mean of the ultimate tensile strength and percent elongation at  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{C}$ ) are shown in Table 4, and are compared with room temperature property data supplied by the manufacturer from the same billet. Cryogenic elastic modulus tests results, shown in Table 3, were performed on several specimens because of the large variation in this parameter exhibited during tensile testing. The ultimate tensile strength (UTS) of the beryllium alloy O-30H appears to have slightly decreased at  $-252.8^{\circ}\text{C}$ , however several of the results were above the value reported for the room temperature result of the same billet. The percent elongation of the beryllium alloy O-30H decreased with decreasing temperature. The UTS is expected to have remained essentially constant at cryogenic temperatures due to the extremely low ductility and notch sensitivity of the material. Unfortunately, traceability of the test specimens within the billet was lost during minor specimen modifications to open the pinhole diameters to accommodate testing.

## 4.0 CONCLUSIONS

### 4.1 AlBeMet162 Conclusions

The ultimate tensile strength and yield strength for extruded AlBeMet162 material increases with decreasing temperature. The percent elongation for extruded AlBeMet162 material decreases with decreasing temperature.

At cryogenic temperatures, the ultimate tensile and yield strength are higher in the longitudinal direction than the long-transverse direction. This is consistent with the room temperature mechanical property data of AMS7912. At cryogenic temperatures, it is not possible to distinguish a difference in percent elongation between the longitudinal and long-transverse directions, whereas there is a difference in percent elongation at room temperature per AMS7912.

The ultimate tensile and yield strengths at  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ) are higher than these properties at  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ). The ultimate tensile and yield strengths at  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) are higher than these properties at  $21^{\circ}\text{C}$  ( $70^{\circ}\text{F}$ ). The elongations at  $-252.8^{\circ}\text{C}$  ( $-423^{\circ}\text{F}$ ) and  $-195.5^{\circ}\text{C}$  ( $-320^{\circ}\text{F}$ ) are lower than the elongation at room temperature.

#### 4.2 O-30H Conclusions

The ultimate tensile strength (UTS) of the beryllium alloy O-30H remained essentially unchanged at  $-252.8^{\circ}\text{C}$  from the room temperature value, and the percent elongation decreased with decreasing temperature. The UTS is expected to have remained unchanged at cryogenic temperatures due to the extremely low ductility and notch sensitivity of the material.

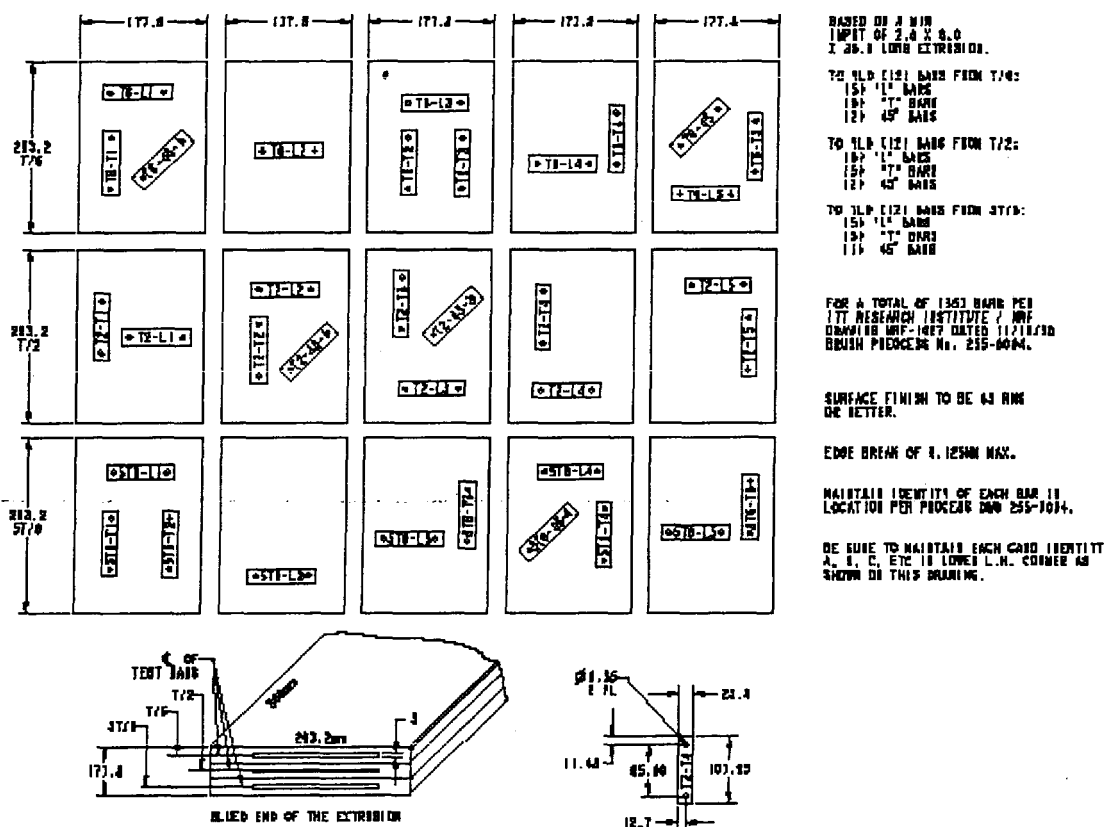


Figure 1: AlBeMet162 specimen extraction locations within the extrusion.

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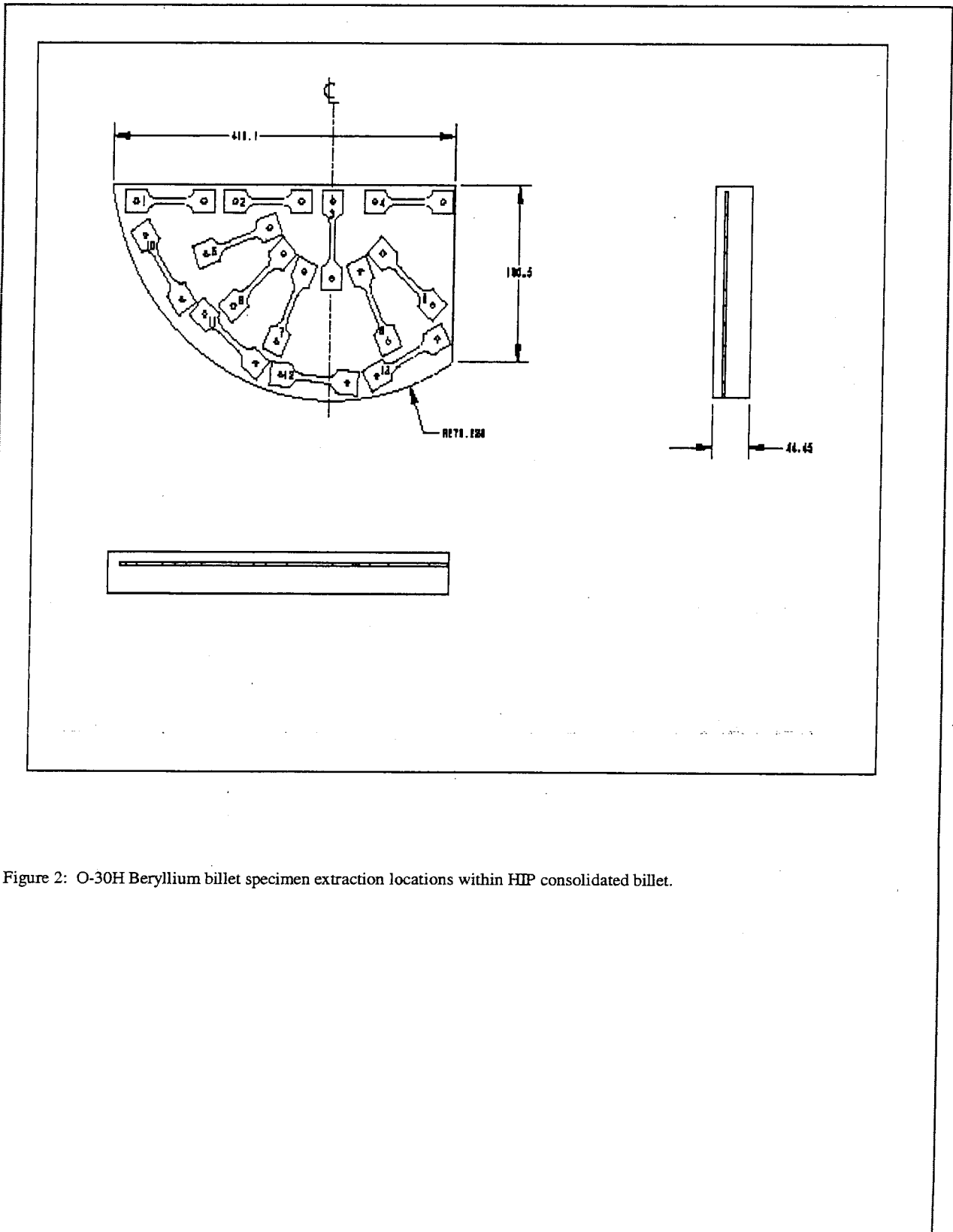


Figure 2: O-30H Beryllium billet specimen extraction locations within HIP consolidated billet.

Table 1: AlBeMet162 Tensile Data at Room Temperature, -195.5°C, and -252.8°C

				.2%		Plastic	Total	Fracture
Other	Orientation	Test	Temp.	Y.S.	UTS	El (1 in)	El (1 in)	Location
ID No.		Type	°C	MPa	MPa	%	%	
T6L1	L	Tensile	21	331.8	451.3	8.1	8.2	center half
T2L5	L	Tensile	21	316.5	432.0	7.4	7.6	center half
5T6L3	L	Tensile	21	317.8	426.8	-	-	outside gage
5T6T4	T	Tensile	21	317.5	377.2	2.3	2.5	center half
T6T5	T	Tensile	21	318.2	389.9	2.4	2.6	center half
T2T3	T	Tensile	21	312.3	372.3	2.4	2.6	center half

				.2%		Plastic	Total	Fracture
Other	Orientation	Test	Temp.	Y.S.	UTS	El (1 in)	El (1 in)	Location
ID No.		Type	°C	MPa	MPa	%	%	
T6-45-1	45	Tensile	-195.5	310.3	456.4	2.5	2.7	end quarter
T2-45-1	45	Tensile	-195.5	327.5	492.3	3.9	4.2	end quarter
T6L2	L	Tensile	-195.5	362.7	530.2	-	-	outside gage
T6L5	L	Tensile	-195.5	366.1	533.7	3.3	3.6	center half
T2L3	L	Tensile	-195.5	347.5	515.0	3.1	3.3	end quarter
5T6L1	L	Tensile	-195.5	355.1	475.7	1.9	2.2	end quarter
5T6L4	L	Tensile	-195.5	384.0	427.5	-	-	outside gage
T2T4	T	Tensile	-195.5	342.0	452.3	1.5	1.8	center half
5T6T2	T	Tensile	-195.5	347.5	439.9	-	-	outside gage
5T6T5	T	Tensile	-195.5	347.5	464.0	1.7	1.9	center half
T6T3	T	Tensile	-195.5	346.8	475.7	1.8	2	end quarter
T2T1	T	Tensile	-195.5	333.7	417.1	0.9	1.1	center half

				.2%		Plastic	Total	Fracture
Other	Orientation	Test	Temp.	Y.S.	UTS	El (1 in)	El (1 in)	Location
ID No.		Type	°C	MPa	MPa	%	%	
T2-45-2	45	Tensile	-252.8	439.2	536.4	1.06	1.36	end quarter
T6-45-2	45	Tensile	-252.8	460.6	572.3	1.26	1.63	end quarter
5T6-45-1	45	Tensile	-252.8	392.3	521.2	1.58	1.83	end quarter
T6L3	L	Tensile	-252.8	474.4	537.1	0.62	0.92	end quarter
T2L1	L	Tensile	-252.8	443.3	517.8	0.73	1.03	end quarter
T2L4	L	Tensile	-252.8	450.2	578.5	1.44	1.7	end quarter
5T6L2	L	Tensile	-252.8	440.6	528.8	0.88	1.15	outside gage
5T6L5	L	Tensile	-252.8	477.1	554.3	0.92	1.26	end quarter
T6L4	L	Tensile	-252.8	404.7	577.8	-	-	outside gage
T2L2	L	Tensile	-252.8	462.6	553.6	1.05	1.3	center half
T6T4	T	Tensile	-252.8	426.8	501.2	0.69	0.96	center half
T2T5	T	Tensile	-252.8	433.7	512.3	0.64	0.96	end quarter
5T6T3	T	Tensile	-252.8	433.0	521.9	0.75	1	end quarter
T6T1	T	Tensile	-252.8	434.4	539.9	0.89	1.17	center half
T2T2	T	Tensile	-252.8	422.0	523.3	0.95	1.21	center half
5T6T1	T	Tensile	-252.8	421.3	496.4	0.88	1.08	end quarter
T6T2	T	Tensile	-252.8	405.4	499.9	0.75	0.995	center half

**Table 2: AlBeMet162 Mechanical Property Mean Summary Data**

Temperature °C	Orientation	No. Specimens	UTS MPa	YS MPa	1" EL
-252.8	L	7	549.7	450.4	1.24
-252.8	T	7	513.6	425.2	1.05
-195.5	L	5	496.4	363.1	3.0
-195.5	T	5	449.8	343.5	1.70
21	L	3	436.7	322	7.4
21	T	3	379.8	316.0	2.6

**Table 3: O30H Beryllium Billet Material Mechanical Property Test Results**

ID No.	Test Type	Temp. (°C)	0.2% Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	Elastic Modulus (Gpa)	1-in Elongation (%)	Fracture Location
50335	Tensile	-252.8	-	-	-	0.0	pin hole
50336	Tensile	-252.8	-	382.76	-	0.5	center half
50337	Tensile	-252.8	-	375.17	-	-	outside gage section
50338	Tensile	-252.8	-	442.76	-	0.4	end quarter
50339	Tensile	-252.8	-	356.55	-	0.2	center half
50340	Tensile	-252.8	-	410.34	-	-	outside gage section
50341	Tensile	-252.8	-	404.14	-	0.2	end quarter
50342	Tensile	-252.8	-	403.45	-	0.4	end quarter
50343	Tensile	-252.8	-	376.55	-	-	outside gage section
50344	Tensile	-252.8	-	404.83	-	0.2	end quarter
50345	Tensile	-252.8	-	411.72	-	0.3	end quarter
50345	Tensile	-252.8	-	-	339.31	-	-
50345	Tensile	-252.8	-	-	330.34	-	-
50345	Tensile	-252.8	-	-	326.89	-	-
50346	Tensile	-252.8	-	386.21	-	0.3	end quarter
50346	Tensile	-252.8	-	-	360.69	-	-
50346	Tensile	-252.8	-	-	360.69	-	-
50346	Tensile	-252.8	-	-	345.52	-	-
50347	Tensile	-252.8	-	417.93	-	0.3	end quarter
50347	Tensile	-252.8	-	-	431.03	-	-
50347	Tensile	-252.8	-	-	399.31	-	-
50347	Tensile	-252.8	-	-	401.38	-	-

**Table 4: O-30H Beryllium Billet Mechanical Property Mean Summary Data**

Test Type	Temp. (°C)	Number of Specimens	Ultimate Tensile Strength (Mpa)	Percent Elongation (%)
Tensile	-252.8	12	397.70	0.26
Tensile	21	1	422.76	2.5

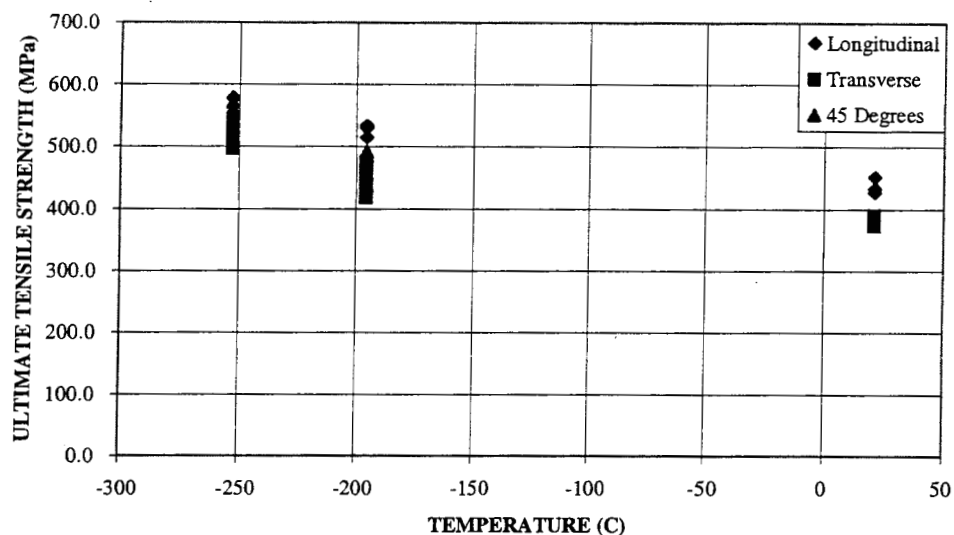


Figure 3: AlBeMet162 ultimate tensile strength versus temperature.

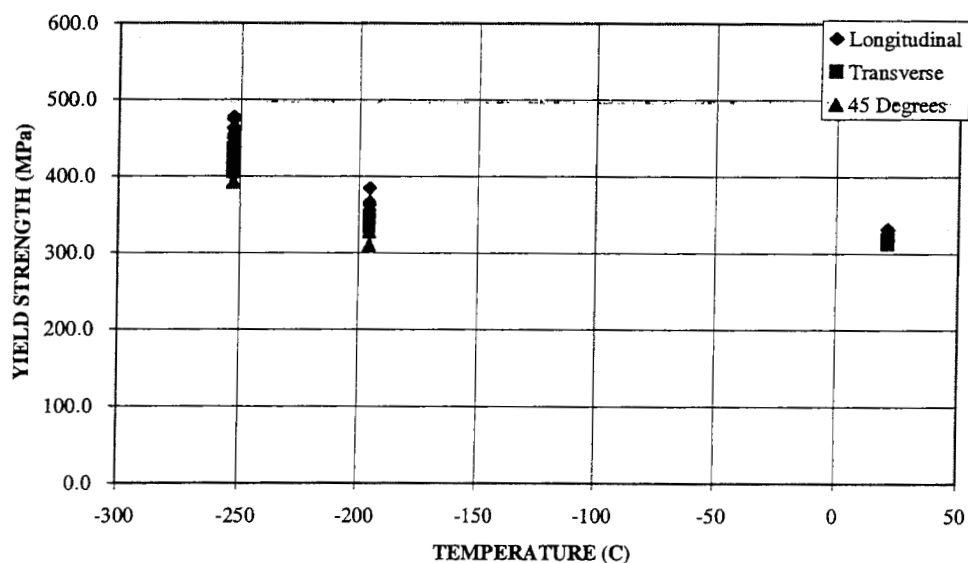


Figure 4: AlBeMet162 yield strength versus temperature.



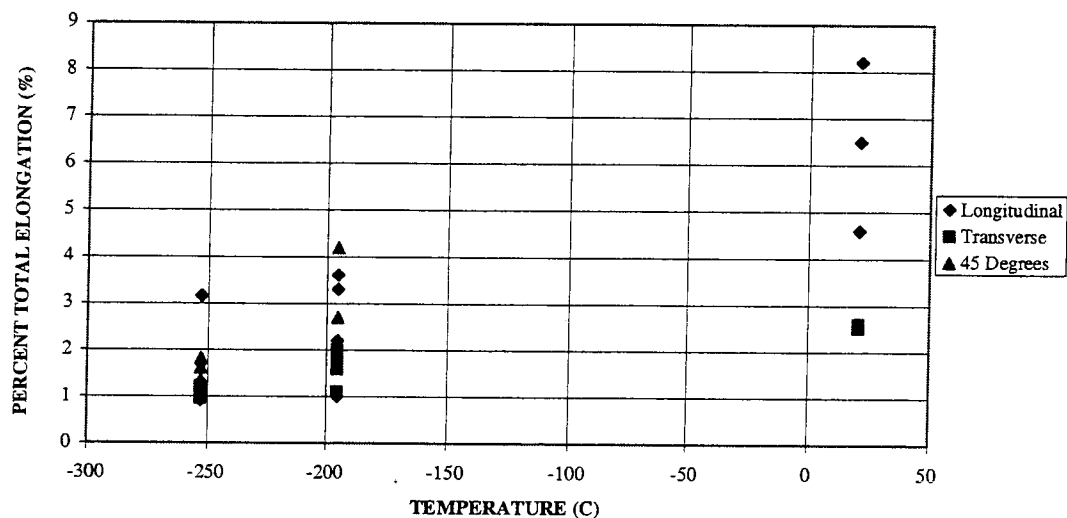


Figure 5: AlBeMet162 percent elongation versus temperature.

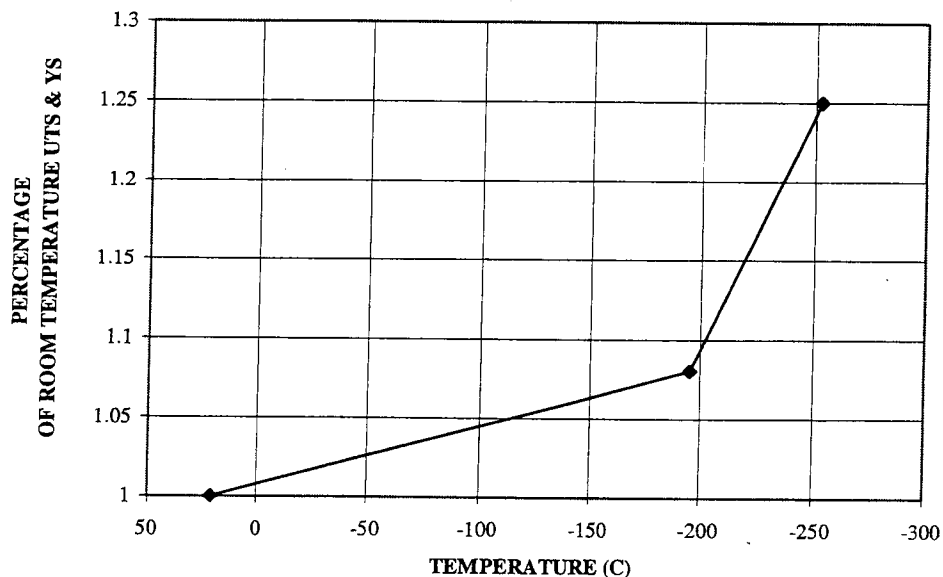


Figure 6: AlBeMet162 design properties for UTS and YS versus temperature.

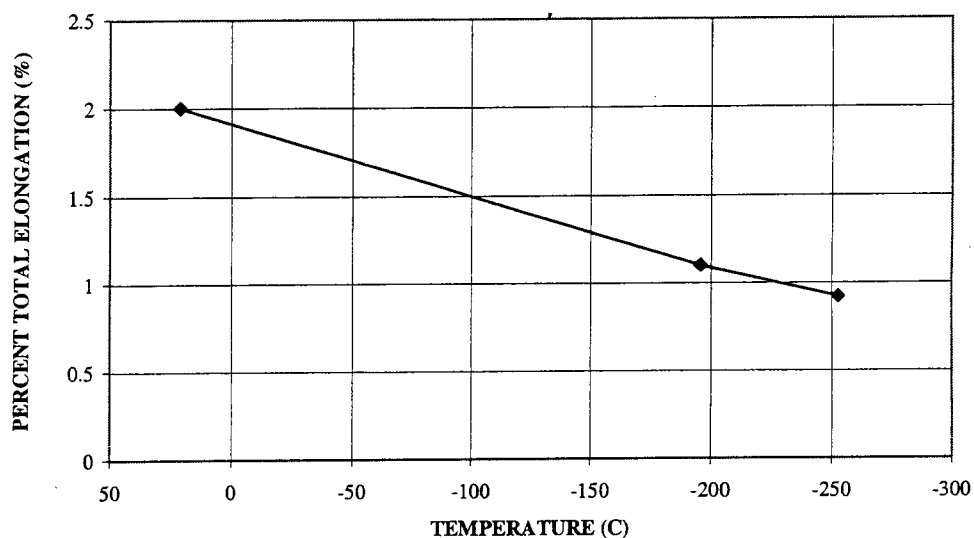


Figure 7: AlBeMet162 design property for percent elongation versus temperature.

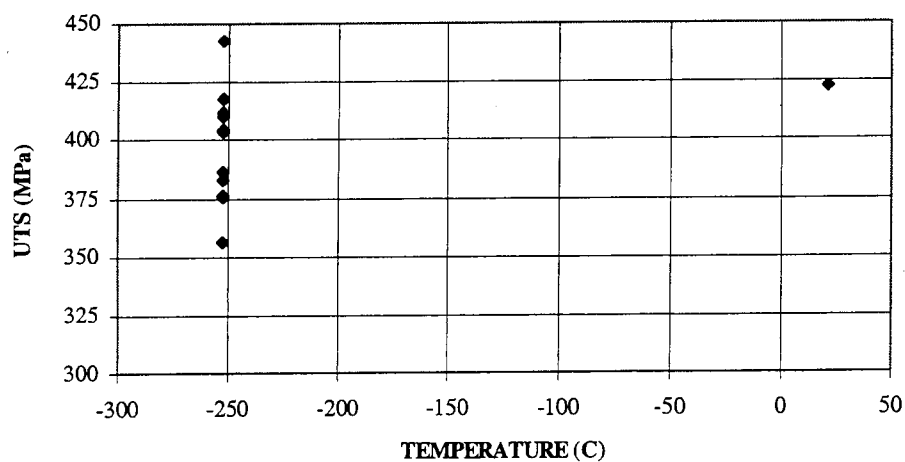


Figure 8: O-30H Beryllium ultimate tensile strength versus temperature.

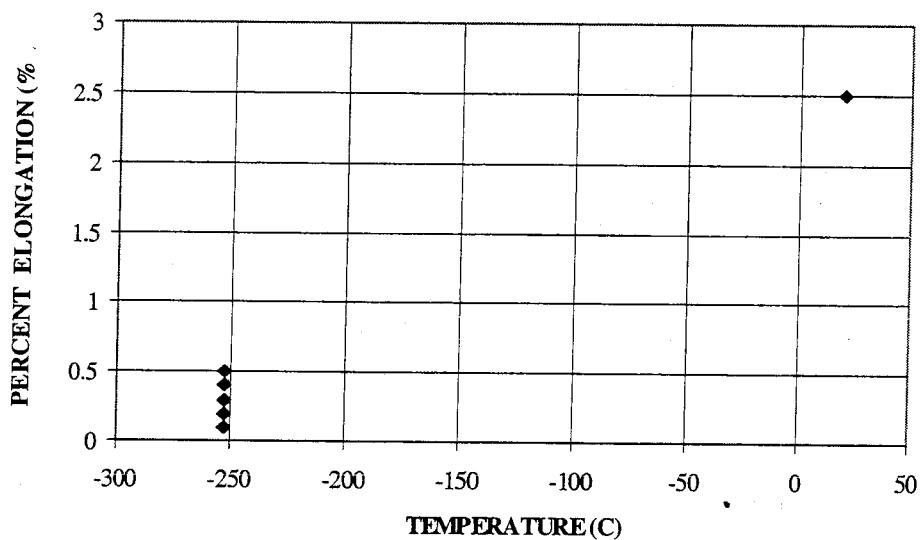


Figure 9: O-30H Beryllium percent elongation versus temperature

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